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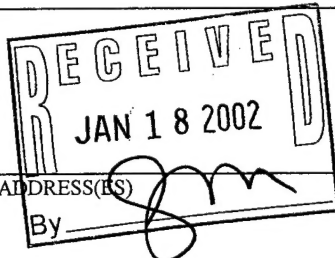
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13. ABSTRACT (Maximum 200 words)

The goal of the research effort in NIMBLE is the design, evaluation, and deployment of information services using the concept of Infostations. The architecture consists of a ubiquitous low bandwidth wireless network which is augmented with convenient and frequent access to isolated high bandwidth connections called **Infostations**. This network supports a "many-time, many-where" communication paradigm that is suited for a wide variety of information services. Different prototypes of Infostations to serve the need of pedestrians and highly mobile users were designed. Downloads of large size files are made possible by strategic placement of Infostations. An additional aspect of this work is our consideration of "asymmetric" transmission to achieve very small, very low cost terminals having very low energy requirements.

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Sincerely,

1 Statement of the problem studied

The current technology of “anytime, anywhere” communication allows low bandwidth wireless communication, which is designed for voice and can only support low grade data services. Providing

capacity wireless bandwidth does not match the expected utilization. Instead, a future wireless architecture in which a ubiquitous low bandwidth wireless network is augmented with convenient and frequent access to isolated high bandwidth connections called **Infostations** was proposed and developed. This network supports a “many-time, many-where” communication paradigm that is suited for a wide variety of information services, such as high speed download of large volumes of

consideration of “asymmetric” transmission to achieve very small, very low cost terminals having

low to medium rate uplinks, introduce additional constraints in application and protocol design.

Access to isolated pockets of high bandwidth connectivity is typically be of very short duration, especially for users moving at vehicular speeds. A typical client operation will be accessing the high bit rate network, downloading information in the shortest possible time, and then being either disconnected or weakly connected. This paradigm implies both the delay of transmission, possibly

the state of the art in network design, network protocols, service organization, and client access protocols.

2 Summary of the most important results

Many-time, many-where communication paradigm, network architecture, and protocols.

Infostation prototypes I, II and III. In Prototype I, the request and the response is through the same infostation. In Prototype II, the protocols were designed for accepting the requests via an ubiquitous low bandwidth link and the download was through the Infostation network. Prototype III allowed transfers to take place across Infostations.

WINMAC protocol: Design, development and implementation of MAC protocol for infostation terminals. The novel ideas incorporated in the WINMAC included rate adaptation to adjust for mobility and dynamic retransmission schemes to adjust for the dynamic loss rate in an Infostation cell.

i.e., drive-through Infostations, to serve users in automobiles; walk-through Infostations, to serve pedestrians; and “sit-through” Infostations to serve stationary users in locations such as an airport lounge.

Mobility based reservation schemes: Resource reservation schemes to aid in real-time delivery of data (voice, video, and multimedia) to highly mobile users. Resource reservation schemes that consider *spatial* and *temporal* resource demands.

Opportunistic protocols: Protocols that can adapt to conditions of the wireless environment such as location and link quality and can postpone action until the desired network connectivity can be established.

2.1 Details of results

1. Implementation of dynamic rate adaptation in WINMAC protocol

The adaptive rate switching algorithm dynamically adjusts the data transmission rate between an Infostation and a mobile terminal to provide the highest possible data link rate. On the fringe of the Infostation coverage area a lower data rate will be selected to provide limited communication for administrative purposes. As the user nears the center of the Infostation coverage area the link data rate automatically increases to exploit the improved channel. The bulk of the download or upload is accomplished at the higher data link rate. Should the channel quality change unexpectedly as the user travels past the Infostation the adaptive rate switching algorithm will automatically track the channel quality changes with a delay of approximately 1 second. The algorithm employs hysteresis to prevent excessive data rate switching.

The Infostation base station broadcasts three beacon packets at the beginning of every 130ms frame. Each of the three beacon packets contain identical data but are transmitted at three

beacons received at each of the three data rates in the previous eight frames. Logic in the mobile terminal examines the values in these three counters on a frame-by-frame basis and determines if a data rate switch is warranted. If so, the mobile terminal uplinks a rate change

the beacon packets. To cover the possibility of a lost rate change request packet the mobile continues to uplink the rate change request until the base acknowledges with the new data rate in the beacon packet.

can be transmitted in a single time slot depending on the currently selected data rate: 30 bytes in a 250kbps slot, 90 bytes in a 500kbps slot, and 444 bytes in a 2Mbps slot. Packets are delivered to the WINMAC at a single maximum size of 444 bytes. Therefore, when operating at less than the 2Mbps data rate, it may be necessary for the WINMAC to sub-fragment packets. Additional WINMAC modules handle the fragmentation and re-assembly of link layer packets.

2. Adaptive Retransmission for WINMAC

The proposed ARQ scheme has three modes of operation based upon the number of times a fragment is received in error and the condition of the channel. The channel condition is characterized by an estimate of the probability that a fragment will be received in error.

where N ($N=N_{frag}$) fragments for one IP packet are sent once. Receiving back a Negative Acknowledgment (NACK), indicates which fragments of this IP packet are received in error. Then, they are retransmitted after the last fragment of the N fragments have been sent.

The second mode (mode 2) or the third mode (mode 3) is adopted according to the value of γ , calculated by the channel condition estimator. The method proposed here is to let γ equal to the ratio of erroneous fragments twice transmitted to the number of fragments, N , that were initially transmitted. If γ is greater than a threshold a (e.g. $a > 0.5$), the transmitter would consider that the fragment error probability of the channel is very high. Therefore all fragments of the IP packet are not likely to be received correctly by any further retransmission. Then the transmitter directly switches to Mode 3 where no additional fragments associated with this IP packet are transmitted. An upper layer or application layer protocol must then decide what to do about this missing IP packet. If γ is less than a , then the channel is judged to be good enough to try one more retransmission. The transmitter switches to Mode 2 in which multiple copies of erroneous fragments are sent in the third transmission.

When γ is between the thresholds a and b ($a > b$), for the third transmission the i number of copies of the erroneous fragment are sent. If γ is less than b , the j number of copies, where $i > j$, of erroneous fragments are sent in the third transmission. After Mode 2, the transmitter goes into Mode 3 even if there are still some fragments of this IP packet

problem of estimating the channel state under rapid fading and multi-user conditions

3. Atomic data transfer over a network of InfoStations.

the entire Infostation infrastructure as a single system rather than viewing it as isolated Infostations. Hence, upload or download of data can be initiated and completed from the entire Infostation network.

To achieve this, all base stations are given the same universal IP on the wireless interface. The applications running on the mobile client now feel as though they are communicating with

and do application sequencing and sequence ordering. Much of the work done by the reliable transfer layer is now done at the application level (much coarser though) except providing reliability. For providing reliability we still rely on TCP. An application level MTU of 25KB

least 25KB can be transferred atomically without migrating from one base station to another. Hence the API breaks up any data segment bigger than this size into chunks of size 25KB and gives these "splits" sequence numbers. The API processes the header and infers the machine on which these various splits should be aggregated before presenting it to the user. This situation could arise since the mobile client could upload various chunks onto various base stations, which then aggregate the various splits based on the sequencing information in them at a particular base station or at a centralized server, which then passes it upwards to the application supposed to receive this data. If the user is downloading a data segment instead then he could potentially download chunks of it from various base stations and then aggregate them to get the whole data segment back. The API running on the infostation infrastructure

base stations and the API on the client takes care of aggregating them and presenting them

from the mobile to the base stations. One of the base stations is treated as the home base where the various splits are aggregated in the case of an upload.

into the application layer itself, and have error correction mechanisms at the application layer

the overhead associated with TCP and its congestion control (which is present now and is undesirable). Another enhancement could be introduce code into the splits itself (inspired from active IP) which could handle the aggregation of the various splits, and also could probably handle the direction and speed of the mobile, so that the infostation architecture could anticipate the next base station with which the mobile will communicate and hence do

bandwidth link that we get between the client and the base station for a small time window.

could now send the appropriate splits to various base stations in anticipation that the mobile will come to these base stations next in its traversal.

3 List of all publications and technical reports:

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 3. "A Conceptual Framework for Network Adaptation", B. R. Badrinath, Armando Fox, Leonard Kleinrock, Gerald Popek, Peter Reiher", M. Satyanaryanan, In ACM/Baltzer Journal on Mobile Network and Applications, special issue on software architectures for mobile applications, Vol. 5, No. 4, December 2000, pp. 221-231.
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- ings of IEEE VTC 2000.

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5 Report of INVENTIONS

1. Infostations prototypes
2. WINMAC protocol for Infostation terminals
3. Rate adaptive MAC for infostations
4. Dynamic error control in infostation access protocols
5. Opportunistic protocol for many-time, many-where communications